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NAVAL RESEARCH REVIEWS

FEBRUARY 1974

PROFILES IN SCIENCE

Dr. Ernest McCormick

Dr. McCormick, who is Professor of Psychology at Purdue University, is well known for his research in the fields of industrial psychology, human factors engineering, and occupational analysis. The Office of Naval Research supports Dr. McCormick's research on structured job-analysis techniques which could result in statistical methods for establishing job aptitude requirements, thus avoiding conventional test validation procedures. The techniques also show promise as means for setting compensation standards.

Dr. McCormick is the author of *Human Factors Engineering*, and co-author with Dr. Joseph Tiffin of *Industrial Psychology*. Both are major publications in the field. Among his many advisory positions, Dr. McCormick is Vice Chairman of the Advisory Board for Personnel Laboratories, under the Naval Research Advisory Committee. He has received the following awards: James McKeen Cattell Award, Division of Industrial Psychology of the American Psychological Association; Franklin V. Taylor Award, Society of Engineering Psychologists; Paul M. Fitts Award, Human Factors Society.

On Scaling Transonic Wind Tunnel Data

R. J. Vidal*

Calspan Corporation
Buffalo, New York

A Short History of Scaling

This history of aviation shows that the wind tunnel has always played a prominent role in developing successful aircraft, and attendant with this role has been the gnawing question of scaling information obtained on a small-scale model to full-scale flight conditions. An early illustration of this question is documented by McFarland in his collection of the papers of Wilbur and Orville Wright. Wilbur Wright wrote a letter to Octave Chanute on December 1, 1901 and discussed some of his wind tunnel measurements of the lift on a wing. He was comparing his results with earlier measurements made by Langley and by Duchemin, and he found that they did not agree. Wright noted "On looking up Langley, I found that he was in agreement with Duchemin. This, you may imagine, disquieted me still more as it seemed to indicate some unsuspected defect in our machine (wind tunnel)". The Wright brothers had encountered a scaling problem which remains a classic problem. They were attempting to measure wing lift under conditions where the wing is stalled and the airflow over the wing upper surface is dominated by large-scale vertical motions which often cannot be reproduced in separate experiments. The laboratory experimentalist has faced similar problems throughout aviation history, and in fact Wright's reaction to the problem, "some unsuspected defect in our machine", is often typical of the reaction by the contemporary experimentalist.

Adequate answers to the scaling problem usually have kept pace with the advancing technology. The basis for the first scaling laws was given originally by Sir Issac Newton in 1726 when he established the inviscid momentum scaling. That is, the forces measured on a model are reduced to coefficient form by dividing by the model area and the momentum flux per unit area of the air stream. The

* is a principal research engineer in the Aerodynamics Research Department of Calspan Corporation. His work has included experimental and theoretical research on subsonic, transonic, and hypersonic flows.

coefficients are then applied to full-scale by multiplying by the area of the full-scale airplane and the free-stream momentum flux per unit area. Unfortunately, Newton sought a general answer to the problem of fluid resistance and had to postulate a simplified molecular model of the fluid. Consequently, his general law did not agree with early experiments, and his momentum scaling appears to have been overlooked in the early aviation research. This is illustrated by the work of Joseph S. Ames (after whom Ames NASA center is named) in which he reintroduced momentum scaling in 1917. It is borne out by de Bothezat who reviewed this scaling in 1918 and remarked that it was a law that was arrived at empirically from a large body of experimental data.

It is possible to trace further the historical development of scaling procedures including the introduction of the Reynolds number to scale viscous or boundary layer effects on airborne vehicles. Air has a small, but finite, viscosity which makes the air particles in contact with the airplane's surface move with the airplane. This viscous motion decays rapidly away from the surface, and viscous effects are largely contained in a thin layer near the surface, termed a boundary layer, which typically is 1 to 2 inches thick. It is interesting to note that the cumulative viscous effects on an airplane are not small, and in fact about half of the airplane's power is required to overcome viscous drag. Consequently, it is important that the influence of viscous effects, or the boundary layer, be preserved when scaling wind tunnel results to full-scale.

The Reynolds number, named after its originator, Osborne Reynolds, is a parameter that can be interpreted as the ratio of inertia or inviscid forces to the viscous forces. It implies that if the full-scale flight Reynolds number is duplicated in the wind tunnel, it is then possible to scale the forces to full-scale simply using the momentum scaling laws. Unfortunately, that is a difficult requirement to meet since the Reynolds number is directly related to the size of the vehicle. Consequently, the requirement frequently is circumvented by simulation techniques.

Another important scaling parameter is the Mach number which governs compressibility effects. These effects arise when the flight speed is comparable with the propagation speed of a pressure disturbance; i.e., the speed of sound in air which is about 660 knots at sea level. For flight speeds that are greater than about half this value, the pressure disturbances from the airplane cannot travel as far ahead of the airplane as at low speeds, say 200 knots. The overall result is that the entire flow field is changed relative to the low-speed flow field. The Mach number, also named for its originator, Ernest

Mach, is the ratio of the flight speed to the ambient sound speed. It implies that scaled model data apply to flight conditions only if the Mach number is preserved; a requirement that usually can be met in wind tunnel experiments.

Scaling techniques have been highly refined in the fifty-six years since Ames' re-introduction of momentum scaling, and in fact, there is some basis for the laboratory experimentalist to feel relatively satisfied with the current state of affairs. However, the fact of the matter is we cannot be completely satisfied because there are important and ostensibly simple flows about subsonic airplanes which cannot be scaled from model to flight conditions.

A Current Scaling Problem

A case in point is the now-classic C-141 problems. The airplane was designed and developed in the traditional manner, and was based in part of testing small-scale models in a wind tunnel in which the flight Mach number was duplicated. The flight Reynolds number could not be duplicated, but suitable and well-established techniques were employed to simulate the Reynolds number. The simulation technique is to roughen the leading edge of the model wing with fine sand or grit particles to artificially produce a thickened turbulent boundary layer similar to that obtained in flight. The airplane was built and flight tested, and it was found that in certain portions of the flight envelope, the tail loads were much greater than expected from wind tunnel tests. The source of this problem, as reported by D. L. Loving at the NASA Langley Research Center, was found to be a rearward shift in the supercritical shock wave on the airplane wing in the flight tests which produced a re-distribution of the aircraft loads.

The basic cause of the problem is illustrated schematically in Figure 1. The flight velocity is subsonic, but the airflow accelerates over the wing to supersonic velocities, typically to a local Mach number of 1.4. Physical laws require that the flow return to a subsonic velocity behind the airfoil. Consequently, a shock wave is formed in the flowfield at some point which is dictated in part by the airfoil shape. The shock wave interacts with the turbulent boundary layer, causing it to thicken which in turn, alters the effective airfoil shape and the position of the shock wave.

The net result is that the interaction produces a bifurcated shock wave, a highly perturbed boundary layer, and a downstream region of separated flow in which the flow is re-circulatory, as indicated in

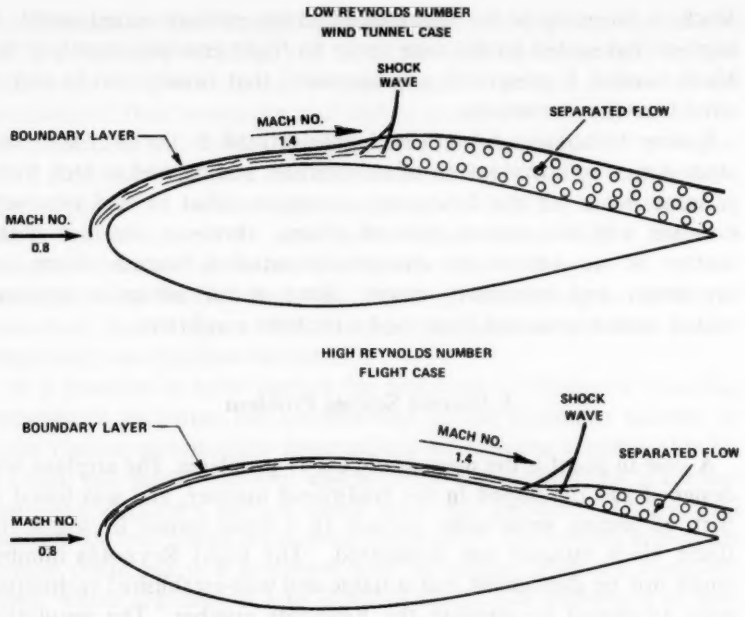

Figure 1 — Scale-effect on shock-induced separation

Figure 1 The separated flow can form a bubble within the main flow (Figure 1) and this changes the effective shape of the airfoil and also the airfoil lift.

With the clarity of hindsight, it can be seen why the C-141 problem originated. Since the Reynolds number could not be duplicated in the wind tunnel, the boundary layer characteristics were not duplicated, and as a result, the mutual interaction between the shock wave and the boundary layer could not be duplicated. The net result was that the shock wave was established at a more forward location in the model experiments, and the downstream separation produced an extensive loss of lift that did not occur in the flight tests. It is interesting to note that the C-141 model was subsequently tested with no roughness on the wing leading edge in order to shed further light on the problem. Those tests, in which no attempt was made to simulate the flight boundary layer, were in good agreement with flight tests, but it is not at all clear why they should agree.

Shock-induced separation is not a new problem and there is a considerable body of literature on the topic. Early experimental studies included the work of Antonio Ferri at Guidonia Italy in 1940, Liepmann and his associates at Cal Tech in 1946, and

Ackeret, Feldman and Rott at Zurich in 1947. Subsequently, additional experimental work has shed considerable light on the phenomenology of the problem and some typical works are cited in the list of References. The important point is that all of this experimental work was performed on small-scale models at low Reynolds number, and there are no basis data available at high Reynolds numbers that are comparable to flight conditions.

This problem of scaling shock wave-turbulent boundary layer interactions is important to current and future generations of airplanes for obvious reasons. We are continuing to develop large airplanes using existing wind tunnels but we are not able to duplicate flight Reynolds numbers in these facilities. Furthermore, we are not able to simulate adequately the high Reynolds number boundary layer for a variety of reasons. This is an undersirable situation, and clearly a solution is required.

There are several potential solutions to the problem. One approach is to develop a new generation of high Reynolds number test facilities. This is being pursued actively in this country and in Europe, but it will be late in the decade before these become available. A second solution is to develop a family of shock-free airfoils with a profile that prevents the shock wave from forming. This approach is being pursued by a number of investigators, including Garabedia and Korn at New York University and Magnus and Yoshihara at the General Dynamics Corporation. These airfoils are successful at the design condition, but at off-design conditions, such as when maneuvering, a shock wave forms and the problem returns.

A third solution, which is being pursued at the Calspan Corporation and sponsored by the Office of Naval Research and the Air Force is to seek scaling laws which could provide a basis for guiding the wind tunnel experimentalist in simulating the high Reynolds number shock wave-boundary layer interaction. In a sense this approach parallels the scaling work performed by Ames and by de Bothezat in that it is based on using a body of experimental data in an effort either to arrive empirically at scaling laws or to provide a basis for establishing theoretical scaling parameters. The important consideration here is that there are no detailed data obtained at high Reynolds numbers on transonic shock wave-boundary layer interactions. The experimental research at the Calspan Corporation is aimed at partially filling that need, and it centers on investigating the shock wave-boundary layer interaction at Reynolds numbers ranging from the wind tunnel condition to conditions exceeding full-scale flight. This experiment and the results to date are

described in a recent paper by Vidal, Wittliff, Catlin, and Sheen. The following summarizes some of those results.

A Simulation Experiment

A laboratory facility which is inherently well suited for high Reynolds number research is the Ludwieg tube, or tube wind tunnel, originated by Hubert Ludwieg at Gottingen in 1955. The present research is being conducted in the Calspan Ludwieg tube which is shown in Figure 2 and is described in detail by Sheeran and Hendershot. The Ludwieg tube is essentially a short duration wind tunnel and it operates as follows. It has a diaphragm station between the supply tube and nozzle, and the latter exhausts into a dump tank. In performing an experiment, plastic diaphragms are inserted at the diaphragm station, the nozzle and dump tank are evacuated to a predetermine pressure, the supply tube is pressurized, and the diaphragms are ruptured mechanically. If one ignores the transient starting process, the test time with the present configuration is 45 to 50 milliseconds, which is more than adequate for the present research. The sketch in Figure 2 shows the facility with a Mach number 2 nozzle installed. A cylindrical, perforated wall nozzle thirty-two inches in diameter is used in the present research and the supply tube and nozzle are translated forward so that the perforated nozzle is entirely contained within the dump tank.

The basic aim in the present research is to impress an airfoil pressure distribution on a flat plate that spans the nozzle, and to study the interaction between a normal shock wave and the turbulent boundary layer that develops on the flat plate, which is the test model. It is fixed in place during the test, as in most wind tunnel tests. Since the perforated nozzle is contained within the evacuated dump tank, there is an outflow through the porous walls during an experiment that produces the equivalent of a supersonic expansion. It is possible to control this expansion by selectively covering the wall perforations and thereby obtain a specified axial pressure distribution in the nozzle.

The nozzle-flat plate arrangement is shown schematically in Figure 3. The leading edge of the flat plate is located slightly ahead of the nozzle throat and the plate extends downstream beyond the nozzle exit. The flow downstream of the nozzle exit is constrained by a rectangular measuring section starting at the nozzle exit to eliminate the nozzle boundary layer. The flow is choked with an adjustable

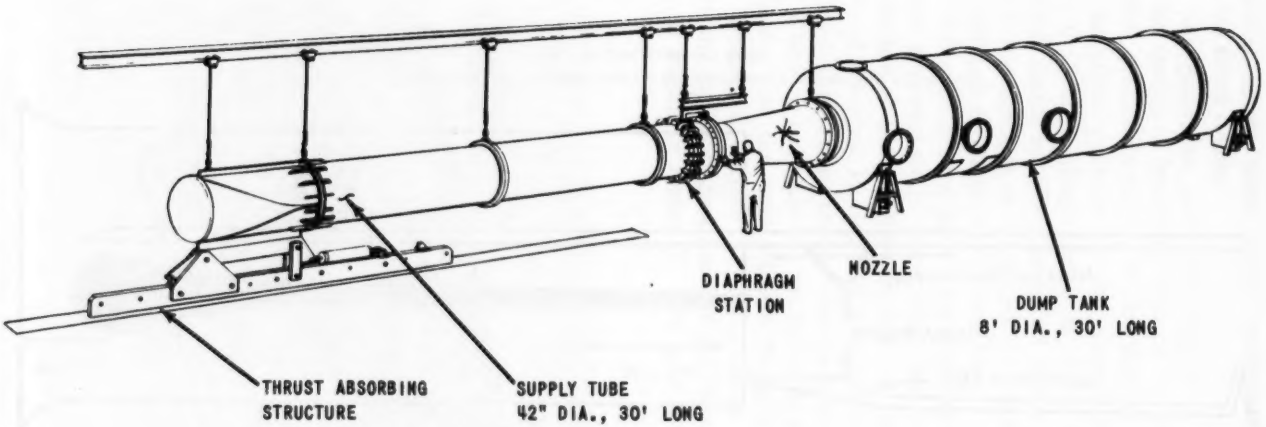

Figure 2 – Calspan Ludwieg tube

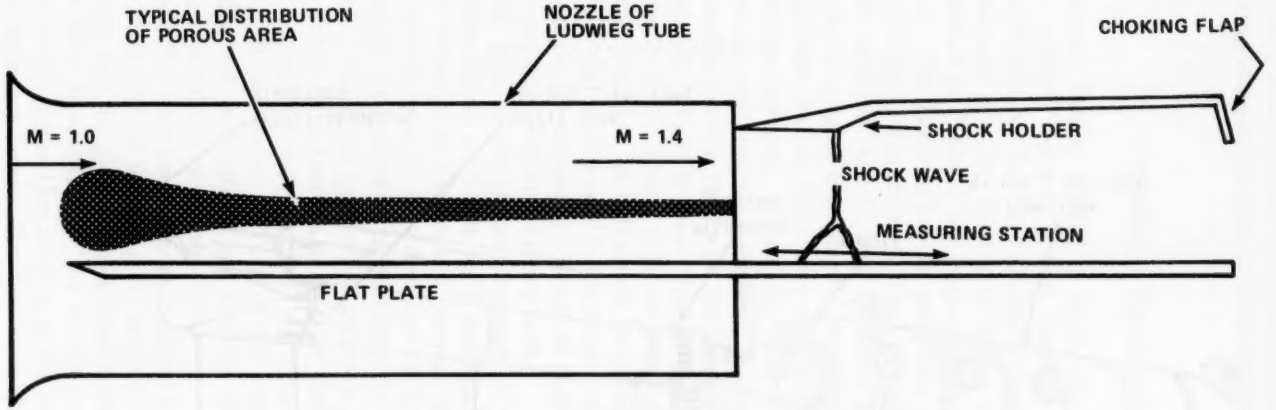

Figure 3 – Schematic of the shock wave–boundary layer interaction experiment in the Calspan Ludwieg tube

flap at the exit of the rectangular observation section, and this produces a normal shock wave which propagates upstream and stabilizes on the shock holder.

There are two points to note with respect to this experiment. First, since the turbulent boundary layer on the flat plate develops under an airfoil pressure gradient, we are duplicating the pertinent features of the airfoil problem in two dimensions. Second, the distance from the plate leading edge to the shock wave is nominally eight feet which means an effective airfoil chord length of sixteen feet, assuming the shock is at midchord. Thus we are essentially studying the full-scale problem in the laboratory.

The model forms an integral part of the Ludwieg tube and consists of a flat plate approximately twelve feet long with a rectangular observation section at the downstream end. A slot is milled down the centerline of the plate so that all instrumentation is internal to the model. Typical instrumentation being used are shown in Figures 4 through 7. The view in Figure 4 is the back side of a plate containing ten pressure and ten skin friction transducers. These are piezoelectric devices developed at the Calspan Corporation for measurements in our short-duration test facilities. A view of the exposed side is shown in Figure 5. The skin friction transducers

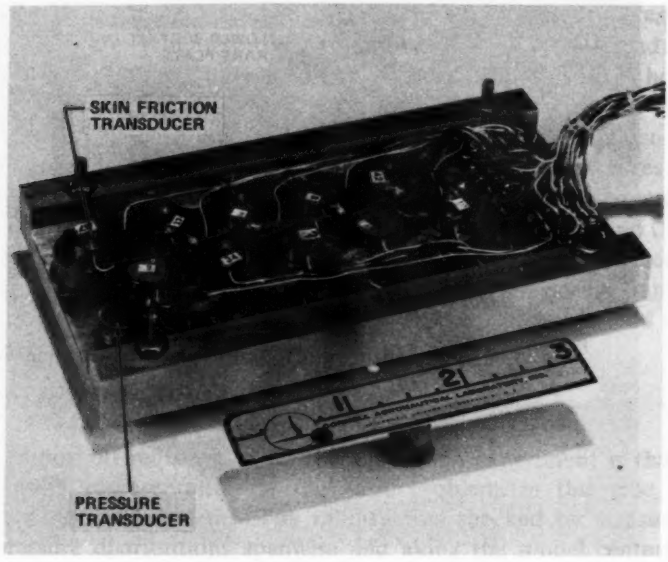

Figure 4 — Underside of the skin friction and pressure survey plate

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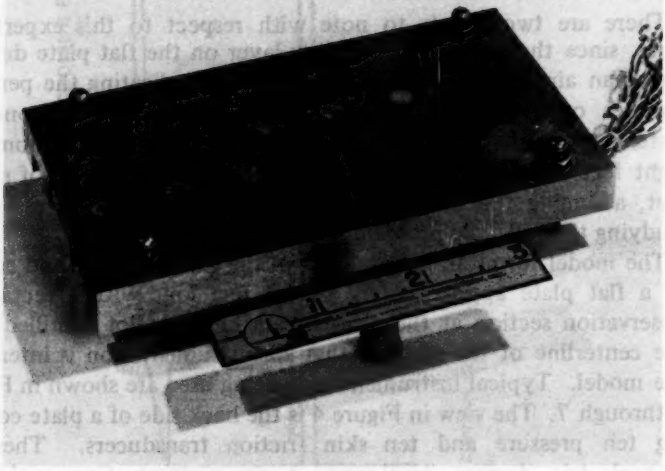


Figure 5 – Exposed surface of the skin friction and pressure survey plate

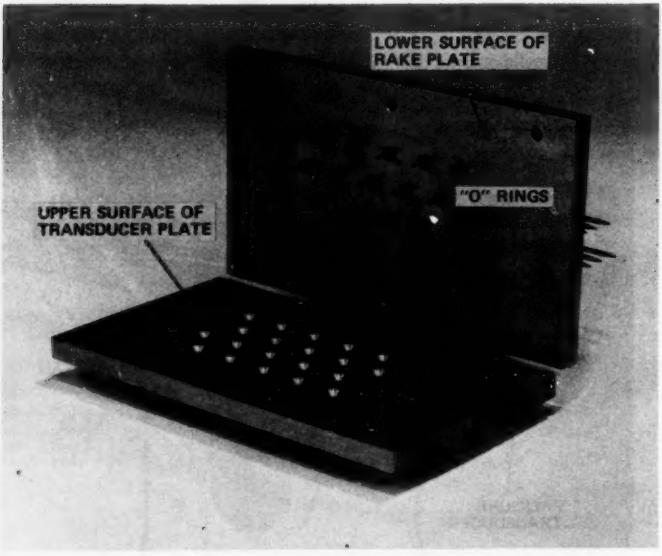


Figure 6 – Survey rake plate assemblies

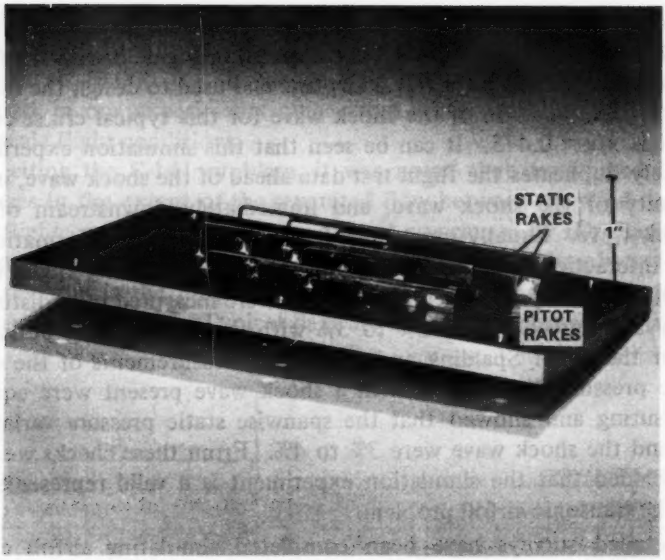


Figure 7 – Typical survey rake

have 1/4-inch diaphragms which are flush with the surface with a small gap around the circumference. The assemblies used to survey the viscous layer are shown in Figures 6 and 7. Twenty pressure transducers are mounted on the undersurface of the transducer plate and are vented to the upper surface through conical holes. The hypodermic tubes from the rake plate are fitted with "O" rings and plug into the conical holes to provide a pressure seal when the plates are clamped together. A total of seven different rakes are used to completely survey the flowfield. The measurements obtained with rakes are pitot pressure and static pressure, and these can be used to determine the local Mach number and the velocity profile in the viscous layer. In addition, a high speed framing camera operating at a rate of 7,000 frames per second is used in a schilieren system to photograph the flowfield.

The Results to Date

An important requirement in any simulation experiment is that it be a valid representation of the basic problem, in this case the transonic airfoil problem. The validity was checked by measuring the pressure distributions spanwise and along the model centerline with a shock wave present, and the boundary layer profiles with no

shock wave present. The measured axial pressure distribution, converted to local Mach number, is compared in Figure 8 with the flight test data obtained on a Naval airplane and used to design the experiment. The position of the shock wave for this typical cruise condition is x/c = 0.475. It can be seen that this simulation experiment closely duplicates the flight test data ahead of the shock wave, in the vicinity of the shock wave, and immediately downstream of the shock wave. Equally important, it provides detailed information in the interaction zone which cannot be obtained during flight tests.

The boundary layer velocity profiles were measured in undisturbed flow and agreed within 2% to 3% with the compressible boundary layer theory of Spalding and Chi. The measurements of the spanwise pressure distribution with a shock wave present were equally reassuring and showed that the spanwise static pressure variations behind the shock wave were 3% to 4%. From these checks we have concluded that the simulation experiment is a valid representation of the transonic airfoil problem.

Detailed surveys have been completed simulating airfoil chord Reynolds numbers of 18 million, 72 million, and 144 million. For comparison purposes, the Reynolds numbers (based on root chord)

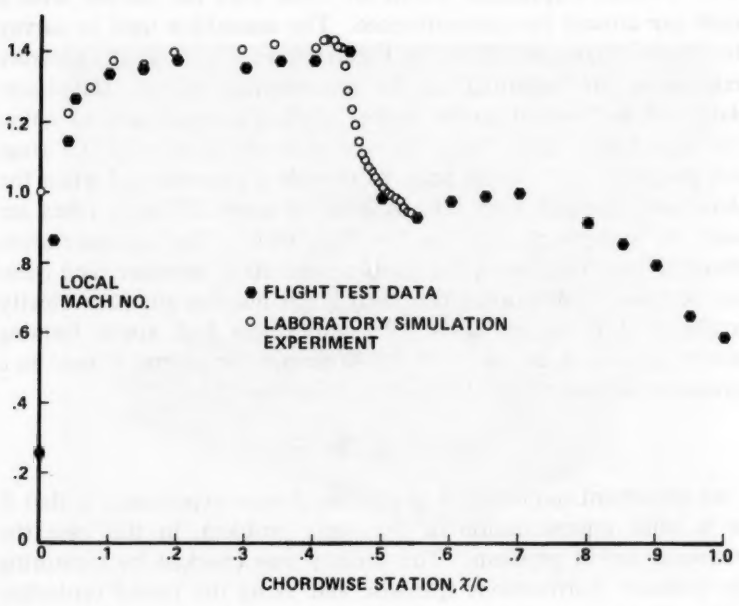


Figure 8 – Local mach number distribituion on a transonic airfoil

for the Grumman F-14 Tomcat cruising at a Mach number of 0.9 area about 140 million at sea level, 82 million at 25,000 ft. and 45 million at 40,000 ft. It can be seen that the Reynolds numbers covered in our experiments range from wind tunnel conditions to full-scale flight conditions.

In citing the C-141 problem, it was noted that it stemmed from changes in the extent of the separated flow between the wind tunnel and flight conditions; in other words, it was caused by the change in Reynolds number. One of the more interesting results observed in our research is the influence of Reynolds number on the length of the separated region. Typical data are shown in Figure 9 and 10 for

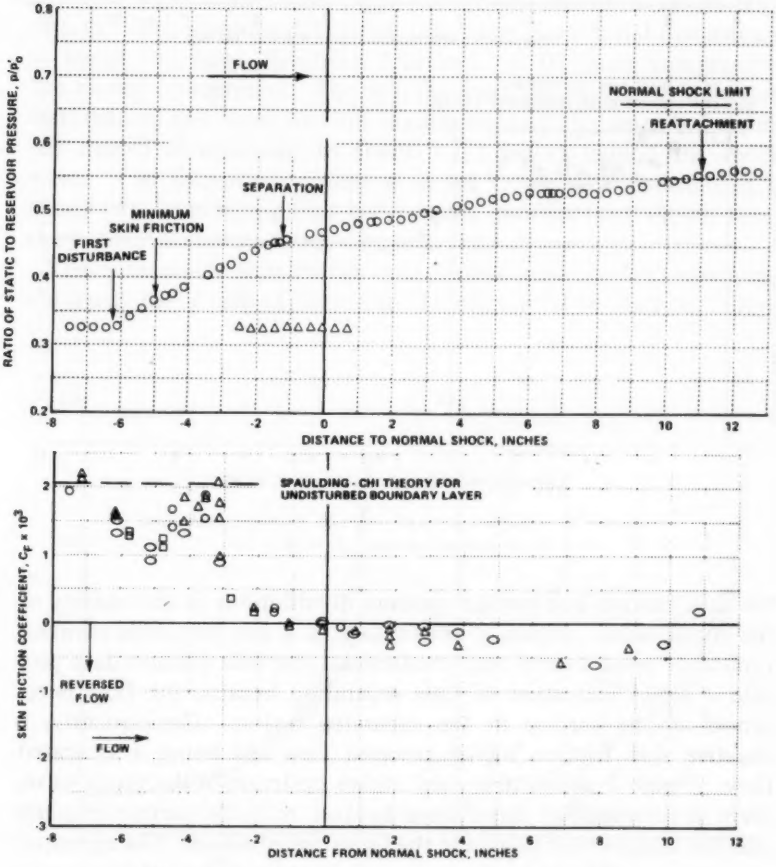
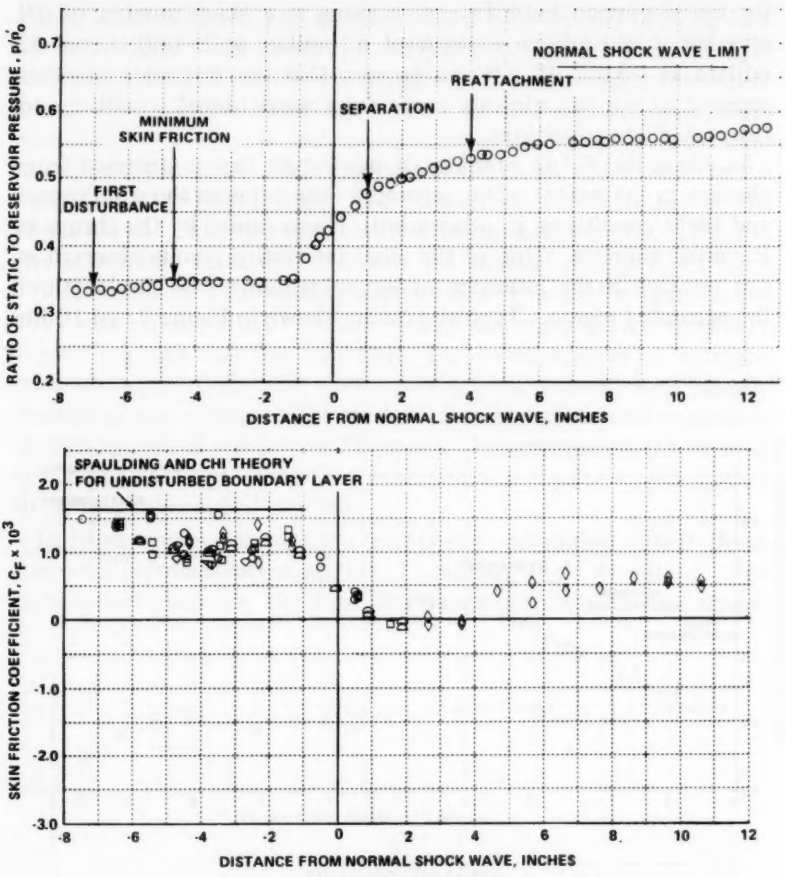


Figure 9 — Surface pressure and skin friction distributions in the interaction zone, $Re = 9 \times 10^6$


RATIO OF STATIC TO RESERVOIR PRESSURE, p/p_o
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SKIN FRICTION COEFFICIENT, $C_F \times 10^3$
DISTANCE FROM NORMAL SHOCK WAVE, INCHES

Figure 10 — Surface pressure and skin friction distributions in the interaction zone, $Re = 36 \times 10^6$

the skin friction and surface pressure distributions in the vicinity of the shock wave. Figure 9 shows data at a low Reynolds number, typical of wind tunnel test conditions. The skin friction data provide a direct indication of flow separation because the flow is reversed at the surface in the separated region. Consequently, a negative skin friction signals reversed flow and hence a separated flow. Figure 9 shows that eight inches upstream of the shock wave, there is no apparent disturbance because both the surface pressure and the skin friction approach the undisturbed values. The approach to separation, for this case, is accompanied by a gradual increase in pressure and an unusual variation in skin friction. Separation occurs

about one inch ahead of the shock wave, as indicated by zero skin friction, and there is a bubble of separated flow extending about 10-1/2 inches downstream of the shock wave. Reattached flow is realized about 11 inches downstream of the shock wave, as indicated by the positive skin friction. The velocity profile data obtained at this condition, Figure 11, show that the region of separated flow is about one third of an inch thick. In short, the separation bubble is a total of about 11-1/2 inches long and about one third of an inch thick.

The corresponding data obtained at conditions approaching flight conditions, a chord Reynolds number of 72 million, are shown in Figure 10. It can be seen that the change in Reynolds number between wind tunnel and flight conditions has some rather large effects. The pressure data show that there is an initial disturbance at about the same chordwise location, but the main compression has moved downstream. The skin friction data confirm an upstream disturbance, and show that the leading edge of the separated region has moved downstream to about 1-1/2 inches behind the shock wave. The important change is in the extent of separation; it is about two inches long, but the velocity profiles (not shown here) show it is still about a third of an inch thick.

The comparable skin friction and surface pressure data have been obtained for a chord Reynolds number of 144 million. This

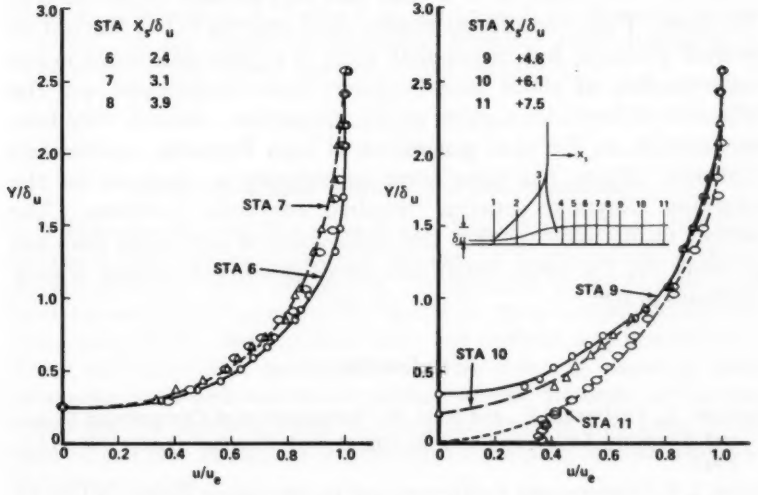

Figure 11 — Viscous layer profiles in the interaction zone $Re_x = 9 \times 10^6$

condition slightly exceeds current flight conditions, but this condition has implications on the current generation of aircraft and is of direct interest for future generations. It was found for this condition that there was a region of separated flow about two inches long, about the same length as at a Reynolds number of 72 million. However, there are indications at this higher Reynolds number that the separated region thinned significantly from the case of 72 million Reynolds number.

To summarize, the experiments that have been completed demonstrate large effects on the extent of shock-induced separation with changing scale. For small-scale or wind tunnel Reynolds numbers, 20 million say, there is a fairly extensive region of separated flow. For Reynolds number comparable to those for the F-14 Tomcat at about 25,000 ft., 70 million, it is found that the separated flow decreases in chordwise extent by a factor of four with almost no change in the thickness of the region. For Reynolds numbers comparable to the F-14 Tomcat at sea level, 140 million, it is found that the separated region is still a factor of four smaller than for the wind tunnel case, but in addition it is significantly thinner.

Implications of These Results

As noted earlier, the research still is in progress and there are plans to expand the scope to include intermediate and higher Reynolds numbers, as well as other simulated flight conditions. Though the results are not complete, it is clear that they do have implications in two areas. First, the present results show that the C-141 was not an isolated problem, but rather that there is a basic deficiency in the understanding of shock wave-boundary layer interactions, and the influence of Reynolds number on the interaction. Second, they have implications on the next generation of high Reynolds number test facilities. There has been some uncertainty in deciding on the maximum Reynolds number required for these facilities. The present results indicate that the shock-induced separation does not go away for the range conditions investigated, but instead it only decreases in size.

References

Ackeret, J., Feldmann, F., and Rott, N. "Investigation of Compression Shocks and Boundary Layers in Cases Moving at High Speeds." *NACA TM 1113.*, 1947.

Ames, J. S.,"Aerodynamic Coefficients and Transformation Tables." *NACA TR 20.*, 1917.

deBothezat, G. "An Introduction to the Laws of Air Resistance of Airfoils." *NACA TR 28,* 1918.

Fage, A., and Sargent, R. F. "Shock-Wave and Boundary-Layer Phenomena Near a Flat Plate." *Proceedings of the Royal Society,* Series A. Vol. 190, pp 1-20, 1947.

Ferri, A. "Experimental Results with Airfoils Tested in the High-Speed Tunnel at Guidonia." *NACA TM* 946, 1940.

Garabedian, P. R., and Korn, D. In "Numerical Solution of Partial Differential Equation, II." Academic Press, New York, 1971.

Holder, D. W., Pearcey, H. H., and Gadd, G. E. "The Interaction Between Shock Waves and Boundary Layers." *ARC Technical Report C.P.* 180, 1955.

Liepmann, H. W. "Interaction Between Boundary Layers and Shock Waves in Transonic Flow." *Journal of the Aeronautical Sciences,* Vol. 13, pp 623-637, 1946.

Loving, D. L. "Wind Tunnel-Flight Correlation of Shock-Induced Separated Flows." *NASA TN D-3580,* 1966.

Ludwieg, H. "Der Rohrwind Kanal." *Zeitschrift für Flugwissenschaften, Vol. 3,* No. 7, pp 206-216, 1955.

Magnus, R. and Yoshihara, H. "Inviscid Transonic Flow Over Airfoils." *AIAA Journal,* Vol. 8, No. 12, pp 2157-2162, December 1970.

McFarland, M. W., *The Papers of Wilbur and Orville Wright,* Vol. 1, McGraw-Hill, 1953.

Newton, I. Philosophiae Naturalis Principia Mathematica (London, 1726), Book II.

Sheeran, W. J., and Hendershot, K. G.,. "A New Concept of a Variable-Mach-Number Perforated Wall Nozzle for Providing a Supersonic External Stream in Rocket Propulsion Testing." *AIAA Paper* No. 66-238, March 1968.

Spalding, D. B. and Chi, S. W. "The Drag of a Compressible Turbulent Boundary Layer on a Smooth Flat Plate with and Without Heat Transfer." *Journal of Fluid Mechanics,* Vol. 18, Pt. 1, pp 117-143, January 1964.

Vidal, R. J., Wittliff, C. E., Catlin, P. A. and Sheen, B. N. "Reynolds Number Effects on the Shock Wave-Turbulent Boundary Layer Interaction at Transonic Speeds." *AIAA Paper No.* 73-661, July 1973.

Diving Data-Bank Workshop at Submarine Base

In February, the Naval Submarine Medical Research Laboratory at the Naval Submarine Base, Groton, Connecticut, was host for an international workshop on Data Banks for Diving Information. The discussion by the 27 participants covered a variety of programs for storing data on diving–computer techniques, diving safety factors, decompression tables and problems, long term effects of diving and many other aspects of the whole picture or recording diving information from both civilian and military sources. Treatment of the great volume and ever-increasing stream of information stored in these computerized banks of data have led to many improvements in the safety and effectiveness of all underwater work.

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A New Method for the Design of Structural Ceramic Components

S. M. Wiederhorn and A. G. Evans*

The safe and efficient design of structural ceramic components such as high voltage insulators, advanced gas turbine components and large electromagnetic windows requires recognition of two major limitations of ceramics; a large variability of strength and the occurrence of slow crack growth. The large strength variability is indicated by coefficients of variation that range from 10 to 20 percent so that, in any batch of ceramic parts, some will have strengths much less than the average (Figure 1). The effective strength is further reduced (Figure 2) by a factor of up to 4 by slow crack growth, which is manifested as a time delay to failure. Both phenomena result in strength uncertainty, and this has constrained designers to use large factors of safety for the design of ceramic structures (as much as 8 for glass; PPG Industries, Technical Service Report 101).

An alternative approach to structural relaibility which has a more rational basis for quantitative failure prediction is the use of proof testing. Proof testing is essentially one way of selecting out the low strength components from any given batch. The Office of Naval Research is supporting the research to develop proof testing methods. By proof testing we mean that a load greater than the expected in-service load is applied to the structural component. Then, in an effective proof test, the load will break the defective parts and leave the good ones undamaged so that they can perform satisfactorily under service conditions. The criteria for an effective proof test are that the stress must simulate the intended service stress and that failures are readily identified when the proof test is complete. In this article, we will describe a basic approach to selecting the proof test load appropriate to any given application. A full derivation of the method and a discussion of its applications to ceramic materials are given in the references.

*Dr. Wiederhorn, who is chief of one Physical Properties Section at National Bureau of Standards, does research in the field of structure, fracture, and deformation of ceramic materials. He has conducted recently projects concerned with the elucidation of the mechanisms of fracture in glass and other brittle ceramics.

Dr. Evans research primarily concerns the application of fracture mechanics ot high temperature structural of plastic flow on fracture. In 1972 he joined the National Bureau of Standards.

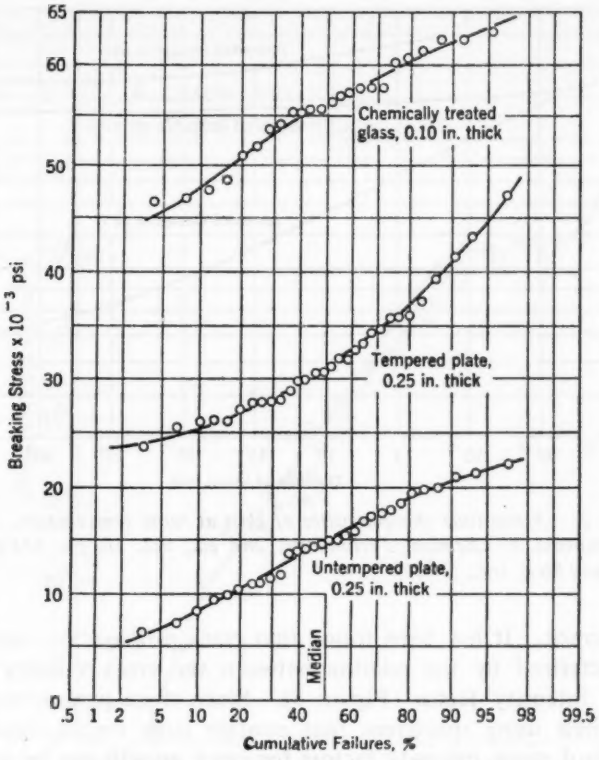

Figure 1 – Typical distribution of breaking stresses of glass. From the Encyclopedia of Chemical Technology, 2nd ed., vol. 10, pp. 533-604, John Wiley and Sons, Inc., (1966)

Mechanical failure of ceramic components is due primarily to the propagation of small preexisting cracks that are always present after fabrication, machining, etc. The crack propagation is usually assisted by moisture in the environment, and rapid failure occurs when the cracks reach a critical size, determined by the physical properties of the ceramic material and the level of the applied load. A prediction of the failure time of the ceramic component may be obtained by characterizing the crack growth behavior and the condition for rapid crack propagation. Thus, criteria for design can be developed from an understanding of the crack growth process.

Fracture mechanics techniques are used to characterize the fracture process. The important fracture mechanics parameter is the stress intensity factor, K_I, which is a measure of the stress at the tip

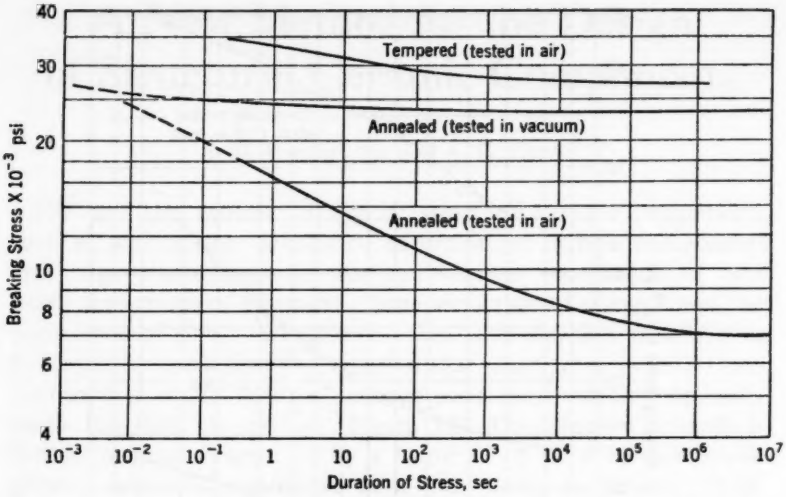

Figure 2 – Stress-time characterisitcs of glass at room temperature. From the Encyclopedia of Chemical Technology, 2nd ed., vol. 10, pp. 533-604, John Wiley and Sons, Inc., (1966)

of a crack. It has been found that crack propagation can be fully characterized by the relation between the crack velocity and the stress intensity factor (Figure 3). Since these parameters can be measured using specimens that contain large cracks, crack velocities and stress intensity factors for crack growth can be accurately determined. These studies also show that the critical conditions for rapid fracture are uniquely determined by a critical value of the stress intensity factor, K_{IC}. By determining K_{IC} and by characterizing the crack velocity in terms of the stress intensity factor, the time to failure for any ceramic component may be estimated, provided information is available on the initial flaw size.

In ceramic materials, proof testing is the best way of characterizing the initial flaw size.* Proof testing subjects the most serious flaw in the component to a stress greater than will be met in service. The specimen will break during the proof test if the stress at the crack tip exceeds the stress for rapid fracture. Since the crack tip stress is directly related to the flaw size, this test sets a limit to the

*The flaw size can also be determined statistically from strength measurements. A method using this approach is also given in the references. However, when the highest assurance of component survival under load is required one must resort to proof testing or other techniques which can be devised to determine the most severe flaw in each separate component.

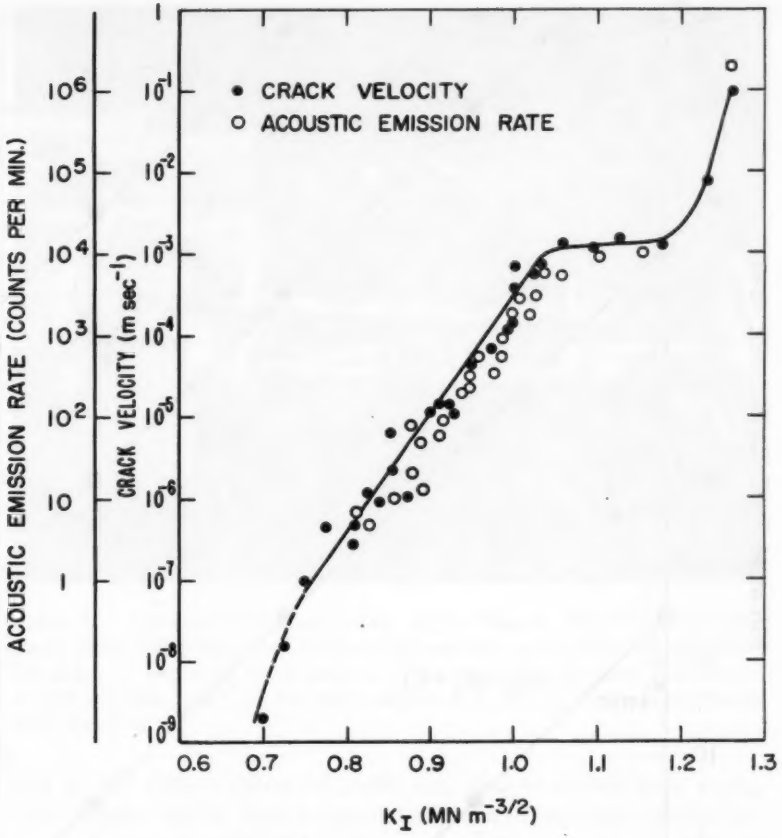

Figure 3 – Crack velocity and acoustic emission rate in porcelain as a function of applied stress intensity factor.

maximum flaw size in the specimen during the test. A minimum time to failure can be thus estimated corresponding to this maximum flaw size. In this way, crack growth data combined with proof testing is used to estimate the time to failure for structural ceramic components.

These ideas have been used to develop proof test diagrams for failure prediction and for the design of structural ceramics. A proof test diagram obtained from crack growth data on porcelain for electrical insulators is given in Figure 4. These data were collected at the request of the Navy (Naval Facilities Engineering Command) to help them analyze the reasons for failure of porcelain insulators intended to support high-voltage radio tower cables (Omega Station

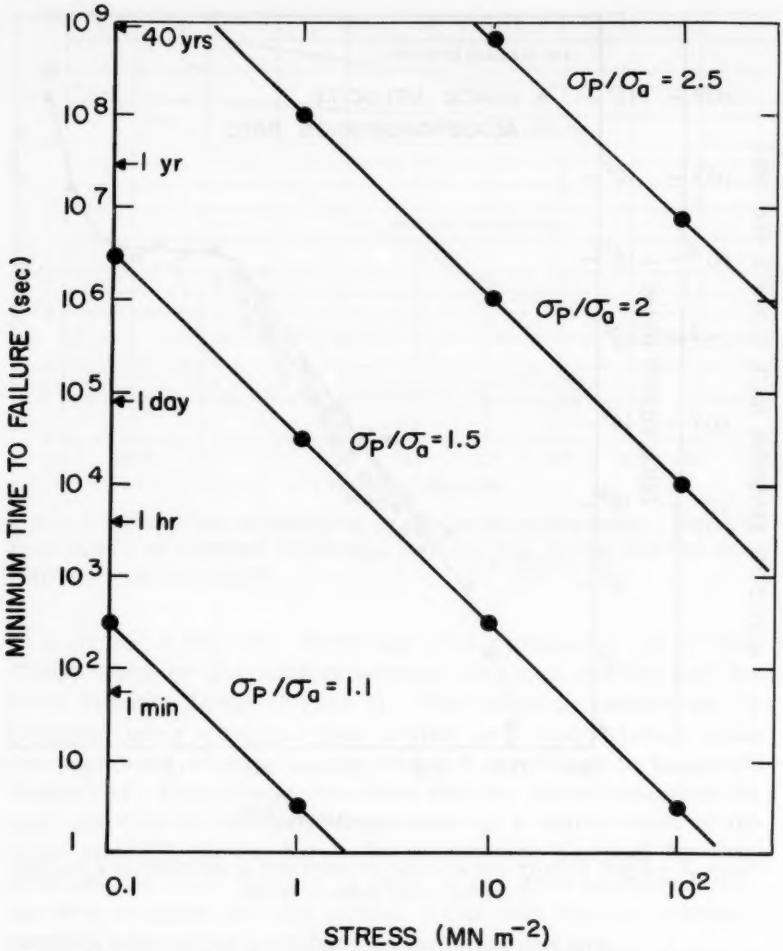

Figure 4 – Proof test diagram for porcelain used as electrical insulators. The minimum expected lifetime is given as a function of stress for a series of different proof test ratios. For an expected service stress of 2,000 p.s.i. (~14 MN/m²) the proof load must be 2,5 times the applied service load of 40,000 pounds to guarantee a lifetime of 40 years.

Valley Span at Haiku, Hawaii, see Figure 5). In Figure 4 the vertical axis gives the logarithm of the estimated minimum time to failure, t_{min} and the horizontal axis gives the logarithm of the service stress that must be supported by the component, σ_a. The straight lines (which have slopes of minus 2) give the relationships between t_{min}

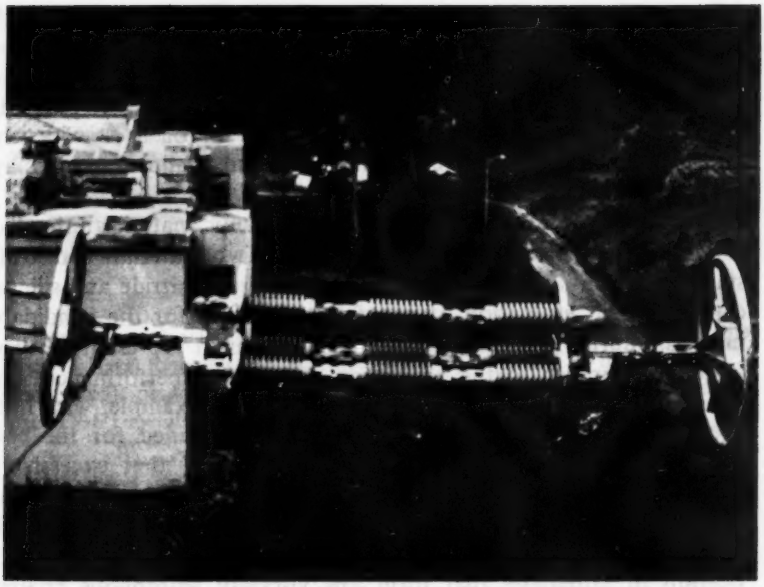

Figure 5 – Omega Station Valley Span, Haiku, Hawaii. The insulators in this figure serve a dual function: Support of load due to the cable; and electrical insulation of the cable from ground. Maximum load on these insulators is 40,000 pounds. Each of the nine insulators in this figure is approximately three feet long.

and σ_a for various ratios of proof test load to service load, σ_p/σ_a. The diagram can be used to predict any one of the three parameters, t_{min}, σ_a, or σ_p/σ_a when the other two are known. Since porcelain insulators usually must support a maximum in-service tensile stress of about 2,000 psi (14 meganewtons per square meters) for about 40 years, a proof test of at least 2.5 times the expected service load is obtained from the figure. Therefore, the porcelain insulators should be subjected to a proof load of two and a half times the Navy in-service load of 40,000 lb to insure structural reliability.

These ideas may be applied in another way to assure structural reliability, particularly if it is found that most of the components fail at the proof stress required for no service failures during the life expectancy of the system. The alternative approach required that each component be subjected to the maximum possible proof stress, for example, the stress at which 1 percent of the components fail. Then, the minimum component lifetime, t_m, for this proof stress is obtained from the proof stress diagram. We know that no service

failures will occur within this period, whereas at longer times a high failure rate is inevitable. Clearly, therefore, the time t_m determines the replacements required for satisfactory performance during the total life expectancy of the system. Although it entails periodic "down-time" and the related expense, this approach is evidently much more tolerable than occassional unexpected failures which may result in total destruction of the system.

This technique is also being applied to ceramic materials intended for use in high temperature gas turbines. Two materials with outstanding potential for this application are silicon nitride and silicon carbide. The evaluation of proof test diagrams for the candidate materials during the early stages of development represents a very effective approach to the prediction of in-service performance, and hence, dictates the selection of materials. For example, with hot-pressed silicon nitride, proof test diagrams obtained for the best material available at the time of testing showed that excessively large proof stresses were needed for satisfactory vane performance at 1400° C. This lead to renewed efforts in materials development, aimed at reducing the slow crack growth rates by reducing the proportion of impurities that form low viscosity amorphous phases. The initial results indicate that these newer materials are much more satisfactory. Once a material with expedient properties has been developed, the proof test diagrams will be used more precisely for the selection of appropriate proof test procedures, as described above for the porcelain insulators.

The design method described above, and illustrated for porcelain and silicon nitride, is applicable to any brittle material that fails by crack growth. The method has been used to check the window design for the Skylab Space Module and will be used to design the windows for the Space Shuttle. Because of its wide applicability and simplicity, the method provides a sound basis for design with brittle materials. Currently, we are developing proof test diagrams for many structural brittle materials, embracing the more mundane applications such as soda lime glass for soda bottles to the more sophisticated applications noted above. It is our hope that these data will form the basis of a handbook for design with brittle materials.

We conclude, therefore, by noting that techniques for design with brittle materials have reached an advanced state of development, and that the advances all emanated from some very fundamental studies of crack propagation rates in brittle materials. Continued research efforts, combined with design studies and practical experience, during the next few years will undoubtedly see brittle materials enter the realm of structural reliability.

References

A. G. Evans and S. M. Wiederhorn, "NBS Report No. NBSIR 73-147", to be published in *Int. J. Fract. Mechanics.*

S. M. Wiederhorn, A. G. Evans and D. E. Roberts, *Proceedings of the Conference on Fracture Mechanics of Ceramics,* Pa. State Univ., July 11-13, 1973.

A. G. Evans and M. Linzer, *J. Am. Ceram.* Soc., October 1973.

Navy Oceanographic Operations

Operations and activities of oceanographic research ships, supported by the Office of Naval Research and currently operating on behalf of the U. S. Navy's oceanographic program are reported below. The ships are identified as Research vessels (R/V) operated by contractors and universities.

The Research Platform FLIP, operated by Scripps Institution of Oceanography and supported by the Office of Naval Research and the National Science Foundation, conducted air-sea interaction research in the Northeast Pacific.

R/V MELVILLE, operated by Scripps Institution of Oceanography and supported by the Office of Naval Research and the National Science Foundation, conducted geochemical and hydrographic research enroute from Pago – Pago to Wellington, New Zealand.

R/V WASHINGTON, operated by Scripps Institution of Oceanography and supported by the Office of Naval Research and the National Science Foundation, conducted heat flow, magnetics, dredging and seismic research in the Mariana Trough and air-sea interaction research in the Northeast Pacific.

R/V VEMA, operated by Lamont-Doherty Geological Observatory (Columbia University) and supported by the Office of Naval Research and the National Science Foundation, conducted dredging, heat flow, and magnetics research along the continental margin off Brazil.

R/V THOMPSON, operated by the University of Washington and supported by the Office of Naval Research and the National Science Foundation, conducted air-sea interaction research in the Northeast Pacific.

R/V CONRAD, operated by Lamont-Doherty Geological Observatory and supported by the Office of Naval Research and the National Science Foundation, conducted geophysical research in the Atlantic – Indian Basin.

Research Notes

Solar Activity Influences Stratospheric-tropospheric Exchange

by R. Reiter

Institute for Atmospheric Environmental Research
Garmisch-Partenkischen, W. Germany

This research note concerning the problem of solar-terrestrial relationships, was prompted by the paper on "Solar Magnetic Fields and Their Influence on the Earth" by John M. Wilcox, appearing in Naval Research Reviews (August 1973).

Under US *AEC* Atomic Energy Commission contract we have been continuously studying stratospheric-tropospheric exchange processes since November 1969. To this end we have been conducting daily round-the-clock measurements of concentrations of the radionuclides Beryllium 7, Phosphorus 32, Phosphorus 33, and Sulphur 35 at a high mountain station at 3 km a.s.l. above see level (Zugspitze Peak, Bavaria (Table I). These radionuclides are generated by cosmic rays in the stratosphere. When a marked increase of Beryllium 7, Phosphorus 32 and others is observed at the measuring station, it has obviously been reached by stratospheric air having penetrated the tropopause at a distance of several hundred or thousand km trajectories being calculated). Such injection into the troposphere occurs in an impulse-like manner at irregular time

TABLE I

		Before Flare	Flare Day	No. of Day after Flare					
				1	2	3	4	5	6
P 32	(a) Frequency in percent of the monthly mean being exceeded	7	16	32	48	44	31	30	23
	(b) Frequency in percent of a peak concentration occurirng	~0	4	13	22	22	12	8	7
Be 7	(a) as above	8	15	30	37	38	29	27	21
	(b) as above	~0	1	15	21	14	12	8	6

intervals of days or weeks. While from our investigations it is gradually becoming clear what the pattern of the tropopause must be like for an injection to occur, the manner in which such injection is primarily triggered is still an open question.

Under ONR contract we have been working for years on the problem of solar-terrestrial relationships in the field of atmospheric electricity. We found that the electric potential between inosphere and earth's surface will significantly increase after solar Hα flares, reaching a maximum on the 2nd or 3rd day after the flare and dropping off subsequently. Relative to the flare-free condition, the increase amounts up to about sixty percent, probably as a result of increased global thunderstorm activity. Inspired by this observation, we studied whether solar activity has an influence on stratospheric-tropospheric exchange also.

It was found that both after solar Hα flares near the center of the sun, and after solar X-ray flares, concentration of Be7 and P32 and other nuclides will increase at our station at 3 km a.s.l. The maximum, which is about twice the concentration under flare-free condition, is observed on the 2nd or 3rd day after the flare. Frequency distribution of high or maximum radionuclide concentrations after flares is apparent from the Table.

We also used the passages of solar magnetic sector boundaries, (which have been postulated by J. M. Wilcox) as key days for superposed epoch analyses. It was shown that on the 4th day after the solar magnetic sector structure is swept past the earth by the solar wind, concentrations of the stratospheric radionuclides in the lower troposphere reach a significant maximum (increase by 70% to 100%).

Noted variations of radionuclide concentration around solar events are in reasonable agreement with the behavior of solar flux in the gigahertz range, of solar wind velocity, the geomagnetic index, and others. Cosmic ray intensity reflecting but slight variations shows that the discovered effects cannot be caused by an increase in production rate of radionuclides.

After the maximum f solar activity during the solar cycle in 1969/1970, solar activity flared up again between August 1971 and August 1972. During this period we identified *particularly* many and rigorous injections of stratospheric air. Furthermore we found, the following significant (more than 99% probability) correlation coefficients:

concentration Be7 in air to sun spot number:	+ 0.62
concentration Be7 in air to solar GHz flux:	+ 0.76

Although it is not possible, as yet, to identify the causative solar-terrestrial process, the discovery of solartropospheric exchange processes being triggered by solar events is fundamental in the following respects:

I. The more intensive the exchange through the tropopause, the shorter the residence time of air pollution in the stratosphere, deposited there e.g. by nuclear explosions, super sonic traffic, rockets, etc. Knowledge of residence time is therefore very important.

II. Injections of stratospheric air into the biosphere can be of consequence if they convey fall-out of high concentrations. Forecasting of such injections and calculating of trajectories can therefore be of practical importance.

III. These studies should be continued with their scope extended in many respects.

Reference

R. Reiter, "Increased Influx of Stratospheric Air into the Lower Troposphere after Solar Hα and X-Ray Flares." *Journal of Geophys. Res. 78.* 6167 (1973).

(Continued from Page 17)

This workshop was jointly sponsored by the Office of Naval Research, the Bureau of Medicine and Surgery and the Underwater Medical Society. Representing these groups were: CAPT C. W. Shilling, MC, USN (Ret) for UMS; CAPT R. Bornmann, BuMed; and Dr. Leonard Libber, ONR.

Discussion of mutual problems proved most fruitful. These problems included efforts toward standardization of data collection, conversion to computer languages, and interchangeability of types of computer systems and related technical difficulties.

A report of the presentations of the Workshop will be made by the NavSubMedRsch Lab covering the 15 papers delivered and summarizing the provocative discussion which took place, and also listing the recommendations generated by the Workshop. This report will be distributed by the Underwater Medical Society, headquartered in Bethesda, Maryland, in accordance with the policies of the Workshop Committee of the UMS.

NRL To Use Outmoded Missiles For Space Research

– The Naval Research Laboratory is expected to enhance its space science program, while saving hundreds of thousands of dollars, by converting phased-out Minuteman I missiles to sounding rockets.

Robert D. Arritt, NRL's program manager for the project, said a number of Minuteman I second stages are being converted into large payload capacity, high performance sounding rockets for x-ray astronomy research. The surplus second stage motors are being adapted with specially designed nose cones and scientific payloads for the forthcoming experiments.

Instruments aboard the new sounding rockets, dubbed the Aries, will be used by NRL scientist to determine the ultraviolet background levels of the stars from above the earth's atmosphere.

The atmosphere's ozone layer at about 100,000 feet absorbs the ultraviolet rays emitted by the stars, so studies of this nature cannot be conducted from the earth's surface.

The feasibility of the novel system was determined in an experimental flight of the Aries, carrying a dummy payload. The test flight was made Oct. 17, 73 from San Nicolas Island, Point Mugu, California. Another test flight is scheduled for May from White Sands, N. M.

The future scientific payloads of the Aries will weigh about 1,800 pounds and will consist of ultraviolet measuring devices, telemetering instruments and a guidance system. They will be hurled into a ballistic trajectory to a height of some 300 miles by the Minuteman I second stage, giving the experimenters the advantage of controlled dwell time out of the atmosphere of about 8 to 12 minutes. A drogue chute will be employed to bring the scientific payload safely back to earth.

The Naval Research Laboratory has been given 72 of the surplus rockets by the Air Force and has asked for options on any others that are available. Minuteman I, the nation's first solid-fuel propelled ICBM has been replaced with more refined and powerful Minuteman II and III missiles.

Rather than destroy the missiles, the Air Force offered its leftover Minuteman first and second stages free to the Naval Research Laboratory and other interested government agencies. One of these other agencies, the Air Force Cambridge Research Laboratory joined with NRL in the test flight at Point Mugu this spring.

Mr. Arritt said the use of the surplus Minuteman I will save the U. S. taxpayers hundreds of thousands of dollars. As a matter of fact, he said, the cost of new missiles for this purpose would be prohibitive under present budget restraints.

NRL has been using rockets for astronomy studies for 27 years. The Laboratory began its investigations with captured German V-2 rockets as early as 1946.

Neutron Radiotherapy for Cancer Patients

– Cancer patients from seven eastern states and the District of Columbia are undergoing neutron radiation therapy in a pilot treatment program using the cyclotron of the Naval Research Laboratory (NRL).

Patients will be selected by physicians at radiation therapy centers in medical centers from Philadelphia to Atlanta. To carry out the program, these radiation therapists, together with biologist and physicists from several universities, laboratories and hospitals have formed a cooperative organization known as the Middle Atlantic Neutron Therapy Association (MANTA). The entire neutron therapy effort at NRL is under MANTA's direction.

Patients from these areas are to be treated with neutron therapy, a type of radiation treatment which may increase the cure rate or control of many kinds of localized malignant tumors. Later in the program, two or three times as many neutron therapy patients may be treated annually.

The NRL cyclotron is a computerized high-energy particle accelerator used in studying radiation effects for the Navy, as well as producing radioactive isotopes for medical and environmental applications. For this program, the high-energy particles being produced – and the resultant radiation beams – are neutrons

(un-charged elementary particles present in all known atomic nuclei except the hydrogen nucleus.)

Contemporary methods of treating cancer – including surgery, radiation with x-rays and gamma rays, and chemotherapy – are relatively successful in curing or controlling certain malignant tumors. Many localized cancers, however, cannot be removed surgically and are not cured by radiation of chemicals. It is now believed that neutron radiotherapy possesses characteristics which may enable this form of radiation to cure or control additional forms of cancer.

While x-rays and gamma rays have been ineffective in destroying those cancer cells characterized by reduced oxygen supply (hypoxic), the neutron beams, it has been discovered, can kill these cells.

The NRL cyclotron is considered an excellent facility for this program, not only because of the favorable characteristics of its neutron beam, but also because of the broad relevant experience of its staff, and the central location of NRL which allows close collaboration among the MANTA members.

The Cyclotron Facility

Five years ago the Naval Research Laboratory cyclotron was completed. Although intended chiefly for basic nuclear physics research for the Navy, planners expected that such a controlled source of high-energy radiation would find other scientific applications.

Other medical applications to date include production of specific radiopharmaceuticals for diagnostic scanning procedures and the rapid radioassay of biological samples.

In preparation for the current neutron therapy program, staff members of NRL studied cyclotron beams both at London's Hammersmith Hospital and at Texas A & M in College Station, Texas. They have enhanced their techniques for the precise determination of the radiation dose delivered to a desired location. Also, they have devised a collimator system to provide precise definition of the area to be treated.

If the anticipated benefits of neutron therapy are demonstrated by clinical trials, it will be possible to draw upon experience with the NRL cyclotron to design subsequent treatment machines at reasonable cost for widespread use in medical centers.

Patient Treatments at NRL

Typically, a patient will receive two treatments a week at NRL for a period of seven weeks. Patients must be ambulatory, and generally will commute from their homes to Washington, or will stay in a nearby hotel during the treatment period or in a Washington area hospital.

The annex for patients, includes rooms for examination and treatment planning. A specially designed shielding maze will eliminate the need for a massive shielding door and thus accelerate the flow of patients to the treatment area.

During the few minutes of treatment, the patient is seated in a chair which is positioned so that the neutron beam is aimed directly at the area of the body

containing the tumor. Since the cyclotron's beam is stationary, the patient can be rotated as required to treat the tumor most effectively. In other forms of radiation therapy, the patient is positioned on a stationary couch and the machine itself may be rotated.

Why Neutron Radiotherapy?

The neutron (an uncharged elementary particle in all known aromic nuclei except the hydrogen nucleus) was discovered in 1932 by English physicist Sir James Chadwick, in a laboratory experiment using radioactive materials. In 1935, Chadwick was the recipient of a Nobel prize for his discovery.

The history of neutron therapy dates from 1938, when approximately 250 patients were treated at two cyclotrons at the University of California, in Berkeley. Although some very advanced cases of cancer apparently were cured, there was a significant incidence of later damage to normal tissues. And for two decades, neutron therapy was abandoned as a form of treatment.

Recent evaluation of the early history of this treatment indicates that – owing to insufficient knowledge of the biological effects of neutrons – these first patients may not have received optimal treatment with neutrons.

In 1968, following a decade of intensive radiobiological research, a new clinical pilot study was initiated at the Medical Research Council Cyclotron at Hammersmith Hospital in London. Two years ago, Hammersmith initiated a controlled clinical trial, the results of which will not be known for several years.

In the United States, neutron therapy has been carried on for the past year at the M.D. Anderson Tumor Institute in Houston, with the cyclotron at Texas A & M, located at College Station, Texas. Within a short time, the University of Washington, in Seattle, expects to place a cyclotron in service for cancer treatment. Perhaps the largest program of neutron beam therapy will be the one in at the Naval Research Laboratory.

Why MANTA?

Extensive clinical trials require large numbers of patients with specific types of tumors. Using statistical methods, some patients are selected to receive neutron therapy; other patients, in order to form a basis of comparison, are chosen to be treated with x-ray and gamma radiation.

No single medical center could reasonably expect to have a sufficient volume of cancer patients to sustain a full-scale, definitive program. It was for these reasons that radiation therapists representing eighteen major medical centers formed the Middle Atlantic Neutron Therapy Association.

Radiotherapists in MANTA and their institutions are:

J. Robert Andrews, M.D.	Veterans Administration Hospital Washington, D.C.
Jose L. Baselga, M.D.	Washington Hospital Center Washington, D.C.

Harry L. Berman, M.D.	Sinai Hospital Baltimore, Maryland
Luther W. Brady, M.D.	Hahnemann Medical College Hospital Philadelphia, Pennsylvania
Patrick J. Cavanaugh, M.D.	Duke University Medical Center Durham, North Carolina
Stanley Chism, M.D.	Walter Reed Army Hospital Washington, D.C.
William C. Constable, M.D.	University of Virginia Hospital Charlottsville, Virginia
James Cox, M.D.	Georgetown University Hospital Washington, D.C.
John C. Evans, M.D.	West Virginia University Medical Center Morgantown, West Virginia
Ulrich K. Henschke, M.D. Ph.D.	Howard University and Freedmen's Hospital Washington, D.C.
David Karp, M.D.	Bethesda Naval Hospital Washington, D.C.
Gustavo Montana, M.D.	University of North Carolina Chapel Hill, North Carolina
John G. Maier, M.D., PhD	George Washington University Hospital Washington, D.C.
John R. McLaren, M.D.	Emory University Clinic Atlanta, Georgia
Milton Raben, M.D.	North Carolina Baptist Hospital Winston-Salem, North Carolina
Charles C. Rogers, M.D. (MANTA Coordinator)	Medical College of Virginia Richmond, Virginia
Keene Wallace, M.D.	Medical University of South Carolina Charleston, South Carolina
Morris J. Wizenberg, M.D.	University of Maryland School of Medicine Baltimore, Maryland

NRL Microwaves Provide Rapid Total Volume Data on Oil Spills at Sea

– Scientists at the Naval Research Laboratory (NRL) report that their multifrequency passive microwave program to determine oil slick thickness at

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sea shows that it may be possible to obtain thickness/volume images over the area of a developing spill on a rapid and operational basis.

The principal conclusions of the study, performed in cooperation with the U. S. Coast Guard, are that oil spills do not spread uniformly, but in small thick regions which cover only a fraction of the visible slick. And multifrequency passive microwave techniques can be used to locate these regions, as well as determine the volume of oil present.

The Coast Guard is using the results of this study in developing a prototype multisensor airborne system as part of its Marine Environmental Protection Program.

This system would provide detailed continuous documentation of the oil location and volume. Knowledge of the volume of oil would be essential for litigation and damage claims resulting from major spills, as well as for assessing the impact of the spill on marine life and environment.

The real-time detailed location of those regions containing the heaviest concentration of oil will promote the most effective confinement, control and clean-up of the oil spill.

The NRL technique will also support the Naval Facilities Engineering Command's effort in developing the Navy's oil pollution and monitoring capability.

The multifrequency passive mircowave technique would be applied to the measurement of oil film thickness in the Environmental Protection Agency's Oil and Hazardous Materials Simulated Environmental Test Tank. The Objective would be to provide the oil film thickness documentation necessary for the evaluation of various oil slick containment and clean-up devices.

NAVAL RESEARCH REVIEWS publishes highlights of research conducted by Navy laboratories and contractors and describes important Naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 109, Office of Naval Research, Arlington, Va. 22217. Requests for subscriptions should be directed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. Subscription price: $4.50 per year in the U.S. and Canada; $5.65 per year, foreign; $0.45 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

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Cover Caption

The Control Room for NRL's cyclotron and ancillary equipment. All adjustments for operation of the equipment are made here. The state of operation of all components is represented visually on the console or on the racks behind the console. A closed circuit television system allows inspection of the cyclotron vault and experimental areas prior to and during operation. See page 29.

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